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Lee et al.

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(54) **ILLUMINATION UNIT WITH A SOLID-STATE LIGHT GENERATING SOURCE, A FLEXIBLE SUBSTRATE, AND A FLEXIBLE AND OPTICALLY TRANSPARENT ENCAPSULANT**

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Related U.S. Application Data

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(51) **Int. Cl.**
F21V 17/06 (2006.01)

(52) **U.S. Cl.** **362/278**; 362/561; 362/570

(58) **Field of Classification Search** 362/561, 362/570, 97, 547, 320, 330, 373, 278
See application file for complete search history.

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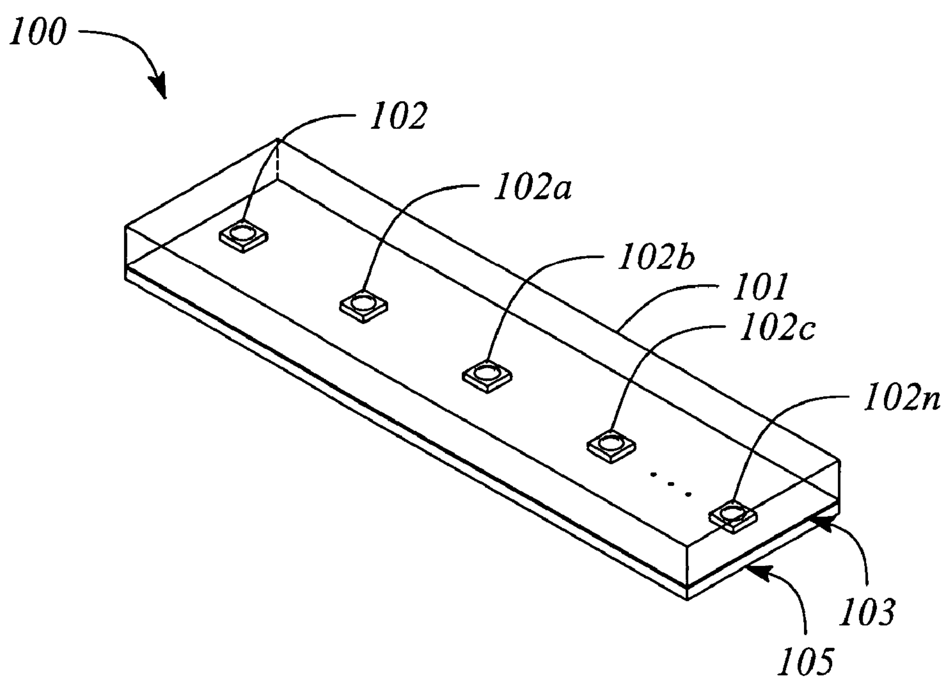
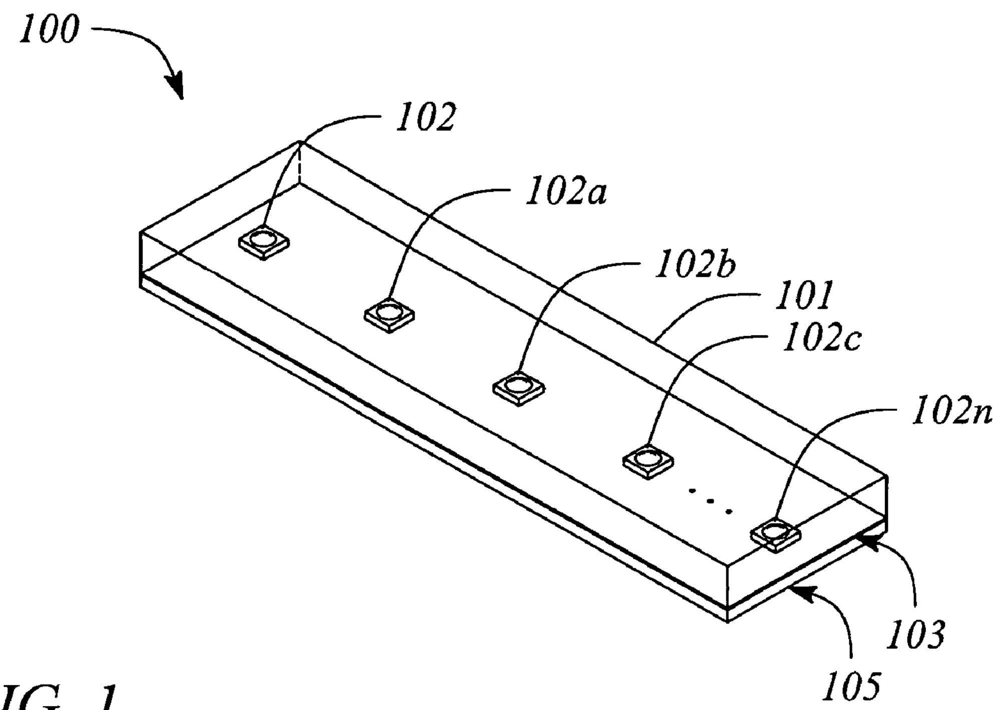
(57) **ABSTRACT**

An illumination unit includes a thin and flexible substrate and flexible electrical tracks formed on the flexible substrate. A number of solid-state light generating sources are arranged on the flexible substrate along the electrical tracks and are electrically connected to the electrical tracks. A flexible and optically transparent encapsulant is provided to encapsulate the light generating sources on the substrate such that the illumination unit is both thin and flexible.

21 Claims, 4 Drawing Sheets




100
102
102a
102b
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102c
102n
103
105

FIG. 1

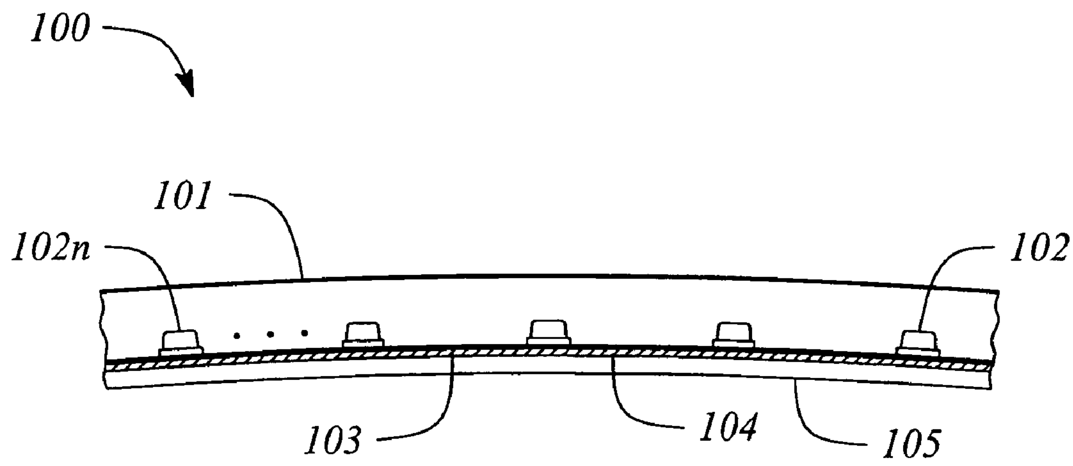
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FIG. 2

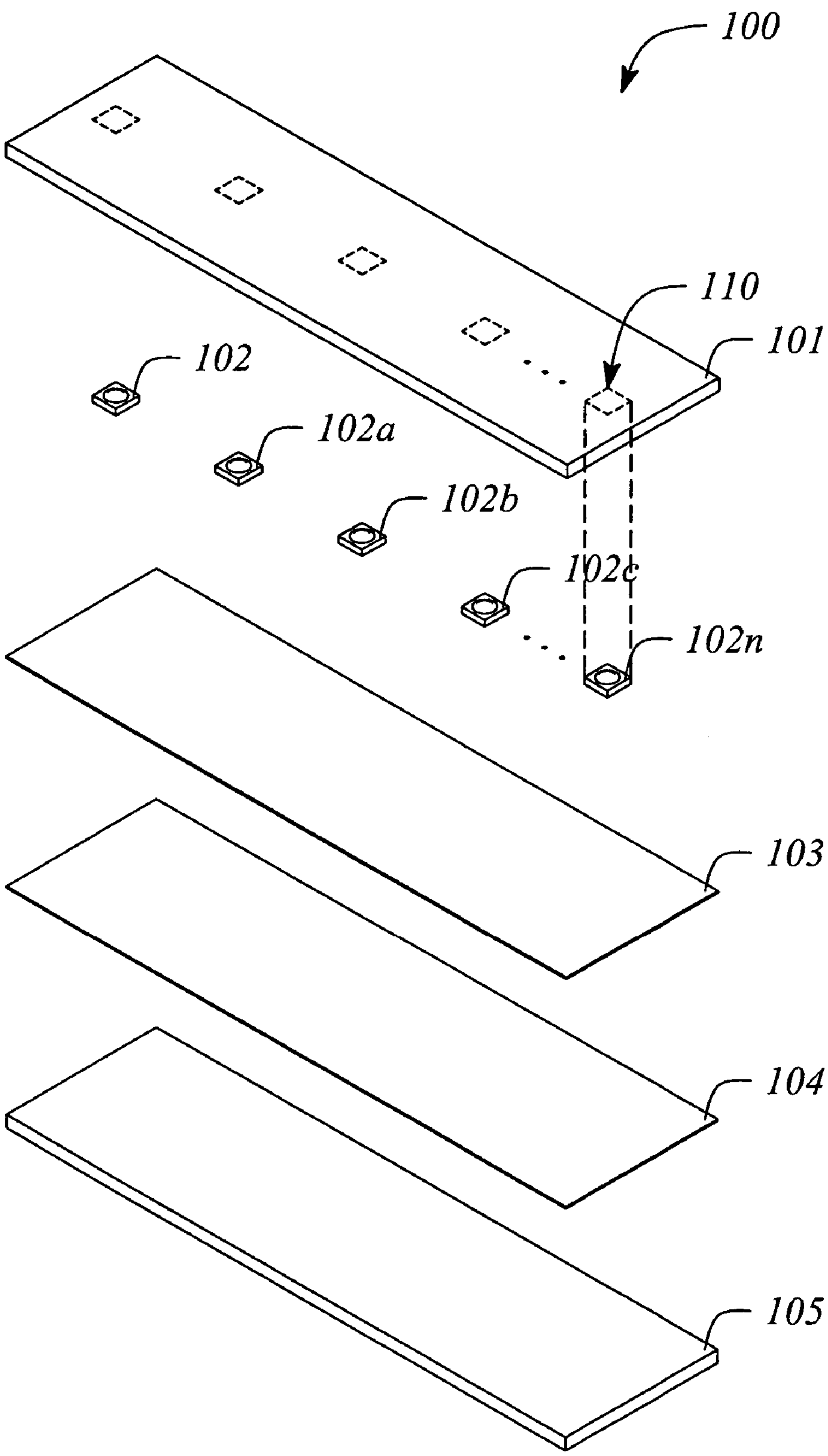

FIG. 3

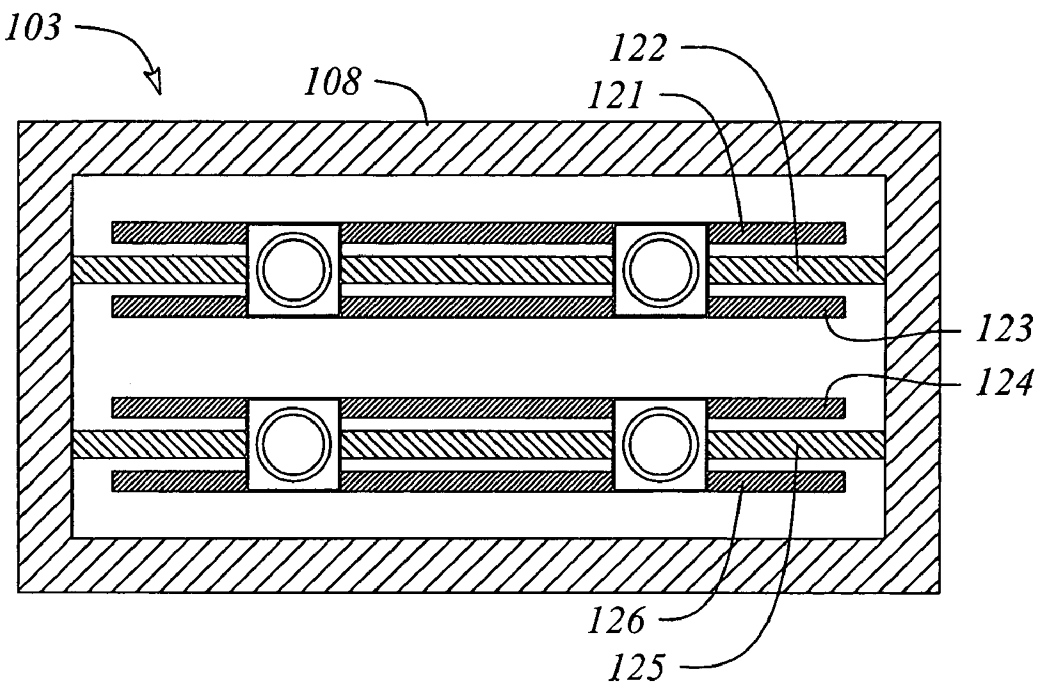

FIG. 4

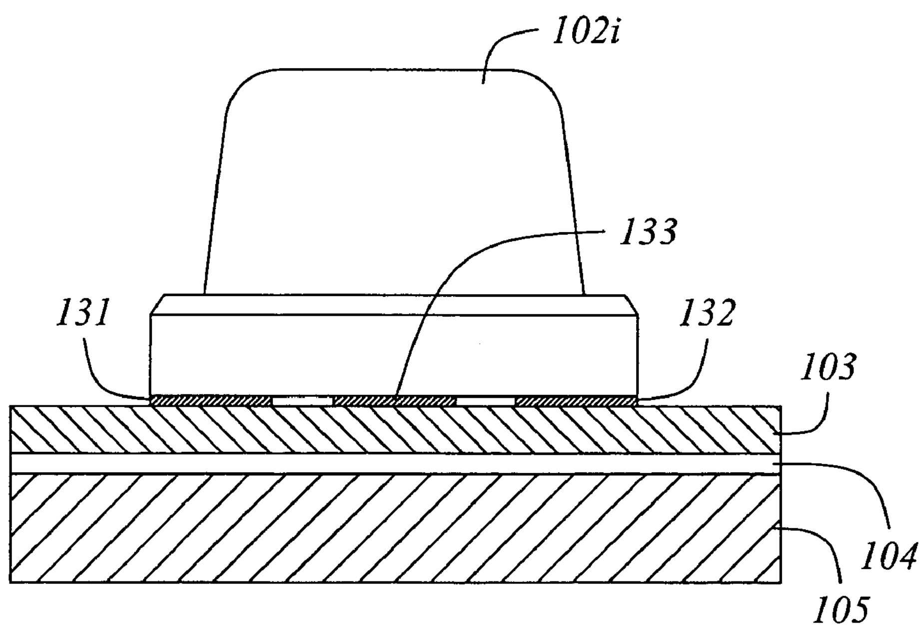

FIG. 5

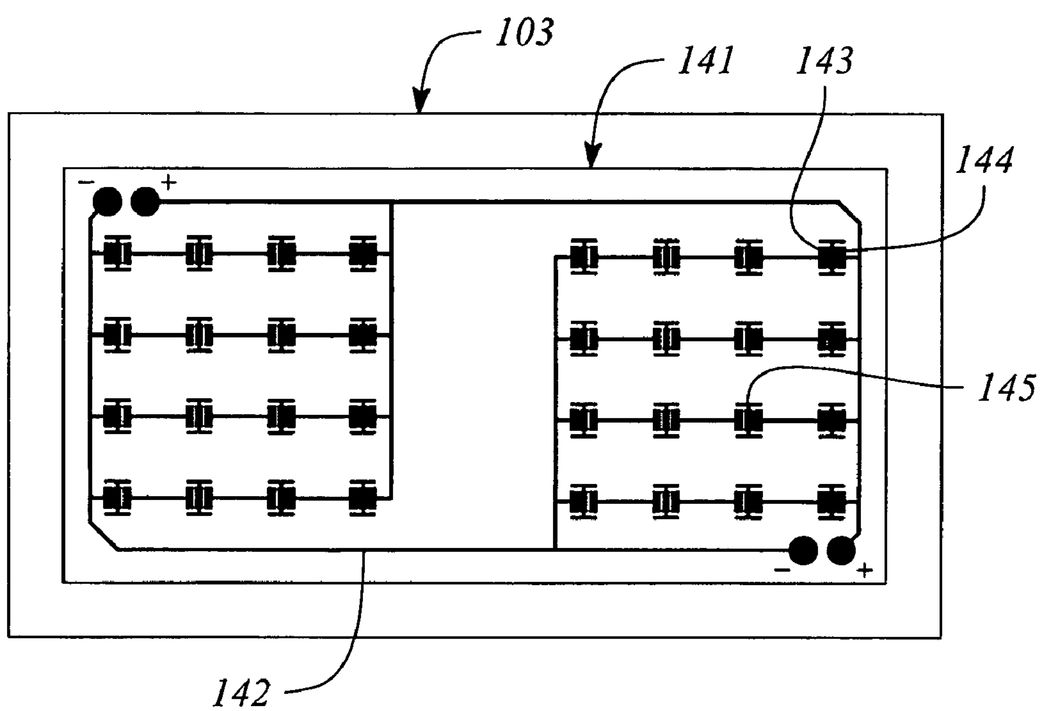

FIG. 6

ILLUMINATION UNIT WITH A SOLID-STATE LIGHT GENERATING SOURCE, A FLEXIBLE SUBSTRATE, AND A FLEXIBLE AND OPTICALLY TRANSPARENT ENCAPSULANT

This application is a continuation-in-part of U.S. patent application Ser. No. 10/434,818, filed May 9, 2003, now U.S. Pat. No. 6,860,620.

TECHNICAL FIELD

The invention relates to an illumination unit. More particularly, the present invention relates to a thin and flexible illumination unit that includes a solid-state light generating source, a flexible substrate, and a flexible and optically transparent encapsulant.

BACKGROUND

Light Emitting Diodes (LEDs) are one type of solid-state light generating devices that have found their way in lighting applications, display applications, photo-therapeutic applications, and other applications where a compact, low voltage, rugged, and high efficiency light source is advantageous. In many such applications, a number of LEDs are arranged into an array or other pre-determined arrangement having similar or dissimilar LED types.

In display applications, LEDs emitting in the red, green, and blue colors are closely packed to form a color "pixel" that blends the three colors. In this manner white light can be generated. Alternatively, by selectively varying the optical output intensity of the three colored LEDs, a selected color can be generated. An array of such "pixels" can form a color display or an illuminating surface emitting white light. In lighting or photo-therapeutic applications, an illumination unit or panel containing LEDs arranged in an array can be formed.

The LEDs can also emit only red, blue or green color, not from the combination of the red, green and blue dies as stated above, but having the individual dies on the package itself emitting the different specific colors.

However, several hurdles remain in the use of LEDs in those applications. One problem associated with the prior LED illumination panel or display is its thickness. This means that the unit must be of the appropriate thickness. For example, a relatively thick LED illumination unit typically affects the therapeutic effectiveness of the unit due to reduced optical intensity. On the other hand, patient safety and comfort may be adversely affected if the unit is made too thin.

The other problem is the rigidity (i.e., not flexible to be bent) of the prior LED illumination unit. As is known, many of the above mentioned applications require that the illumination unit to be flexible. For example, in the lighting application where the LED illumination unit is used as a vehicle lamp, the illumination unit needs to be flexible or soft enough to form a desired shape or contour to follow the contour of a vehicle lamp. In the photo-therapeutic applications, the unit must be flexible enough so that it can follow the contour of the human body part in order to provide safe but effective phototherapy to that body part.

Therefore, what is needed is a thin, flexible, and safe illumination unit.

SUMMARY

One feature of the present invention is to provide an illumination unit having a solid-state light generating source, a flexible substrate, and a flexible and optically transparent encapsulant.

In accordance with one embodiment of the present invention, an illumination unit is provided that includes a thin and flexible substrate and flexible electrical tracks formed on the flexible substrate. A number of solid-state light generating sources are arranged on the flexible substrate along the electrical tracks and are electrically connected to the electrical tracks. A flexible and optically transparent encapsulant is provided to encapsulate the light generating sources on the substrate such that the illumination unit is both thin and flexible.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a perspective view of an illumination unit according to one embodiment of the invention.

FIG. **2** shows a side cross-sectional view of the illumination unit as shown in FIG. **1**.

FIG. **3** shows an exploded view of the illumination unit of FIGS. **1**–**2**.

FIG. **4** is a plan view of a partial circuit layout on a flexible substrate of the illumination unit of FIGS. **1**–**3** in accordance with one embodiment of the present invention.

FIG. **5** is a cross-sectional view of a portion of the illumination unit of FIGS. **1**–**3**, showing a surface-mounted solid-state light generating source on the tracks (both electrical and heat sink tracks) on the flexible substrate.

FIG. **6** is a plan view of a circuit layout on a flexible substrate of the illumination unit of FIGS. **1**–**3** in accordance with another embodiment of the present invention.

DETAILED DESCRIPTION

FIG. **1** shows an illumination unit **100** that implements one embodiment of the present invention. In accordance with one embodiment of the present invention, the illumination unit **100** includes a number of solid-state light generating sources (e.g., light generating sources **102** through **102***n*) arranged on a thin and flexible substrate (i.e., the substrate **103**). A flexible and optically transparent encapsulant **101** is then provided to encapsulate the light generating sources **102**–**102***n* on the substrate **103**. Thus, the illumination unit **100** is both thin and flexible.

This thin and flexible illumination unit **100** can be used in a wide range of applications (e.g., photo-therapeutic, display, or lighting) where a compact, low voltage, rugged, and high efficiency light source is advantageous. For example, the illumination unit **100** can be employed to is build a motor vehicle lamp. In a further example, the illumination unit **100** can be a display panel or a photo-therapeutic unit. In one embodiment, the illumination unit **100** has a thickness of less than 8 mm.

In addition, as the whole illumination unit **100** is flexible, it can be bent to a desired shape or contour, i.e. it can be easily formed to follow the contour of a transparent part of a corresponding lamp. The illumination unit **100** in accordance with one embodiment of the present invention will be described in more detail below, also in conjunction with FIGS. **1**–**6**.

Referring to FIGS. **1**–**6**, the illumination unit **100** is shown to have the encapsulant **101**, the solid-state light generating sources **102**–**102***n*, the flexible substrate **103**, a thermal conductive tape **104**, and a heat sink plate **105**. Tracks (i.e., **121**–**126** in FIG. **4** or **141**–**145** in FIG. **6**) are arranged on the substrate **103** and the substrate **103** is attached to the heat sink plate **105** via the tape **104**.

FIG. **3** shows the exploded view of the illumination unit **100** (without showing the tracks on the substrate **103**). FIG. **3** also shows recesses (e.g., the recess **110**) of the encapsulant **101** that receive the solid-state light generating sources (e.g., the light generating source **102***n*). In one embodiment, the recesses are formed when the encapsulant **101** is formed on the substrate **103** with the light generating sources **102**–**102***n* already mounted thereon. FIG. **4** shows the partial and illustrative layout of the tracks (i.e., the tracks **121**–**126**) in accordance with one embodiment. FIG. **5** shows how each of the light generating sources **102**–**102***n* is mounted on the tracks (e.g., the tracks **121**–**126** of FIG. **4** or the tracks **141**–**145** of FIG. **6**) on the flexible substrate **103** that is attached to the plate **105** via the adhesive tape **104**. FIG. **6** shows the illustrative layout of the tracks (i.e., the tracks **141**–**145**) in accordance with another embodiment.

The substrate **103** is a thin and flexible substrate. This means that the substrate **103** can be made of a film or foil material, and can be easily bent by hand. The substrate **103** may be made of an electrically insulating material.

In one embodiment, the flexible substrate **103** is made of a synthetic material (e.g., polyamide). A substrate made of the above-mentioned polyamide can provide for a sufficient electrical insulation as well as for a sufficient flexibility and strength. In another embodiment, the flexible substrate **103** is made of any electrically non-conductive but thermally conductive material (e.g., silicone or plastic sheet).

In one embodiment, the flexible substrate **103** is a flexible printed circuit board. In another embodiment, the flexible substrate **103** has a thickness of about 25.4 micrometers. Alternatively, the substrate **103** may have other thickness.

In addition, the illumination unit **100** may also include a heat sink frame **108** on the substrate **103**. In one embodiment, the heat sink frame **108** surrounds the substrate **103**. In another embodiment, the heat sink frame **108** is on the top and bottom surfaces of the substrate **103**. In a further embodiment, the heat sink frame **108** is on one of the top and bottom surfaces of the substrate **103**. The heat sink frame **108** may be made of metal.

The heat sink plate **105** that may serve both as heat sink and base support for the substrate **103**. Alternatively, the illumination unit **100** may not include the heat sink frame **108** or the plate **105**. In one embodiment, the plate **105** is a heat conducting metal plate or sheet attached to the substrate **103** via a thermally conductive adhesive. This means that the adhesive tape **104** can be thermally conductive adhesive. In another embodiment, the plate **105** is replaced with a heat conducting ceramic plate or sheet.

The flexible tracks (e.g., the tracks **121**–**126** in FIG. **4** or the tracks **141**–**145** in FIG. **6**) are formed on the flexible substrate layer **103**. The tracks include electrical tracks (e.g., the tracks **121**, **123**–**124**, and **126** in FIG. **4** or the tracks **141**–**144**) and heat sink tracks (e.g., the tracks **122** and **125** in FIG. **4** or the track **145** in FIG. **6**). The tracks may be arranged in a predetermined pattern on the substrate layer **103** in accordance with a desired light form and intensity.

Referring to FIG. **4**, the tracks **121**–**126** include electrical tracks (e.g., the tracks **121**, **123**–**124**, and **126**) and heat sink tracks (e.g., the tracks **122** and **125**). Each of the electrical tracks is of a conductive material (e.g., metal). The tracks may be arranged in a predetermined pattern on the substrate layer **103** in accordance with a desired light form and intensity.

The electrical tracks (e.g., the tracks **121**, **123**–**124**, and **126**) include at least an anode track or trace (e.g., the track **121** or **124**) and a cathode track or trace (e.g., the track **123** or **126**) extending parallel to each other. An anode terminal and a cathode terminal of a corresponding light generating source are attached to the corresponding tracks. Therefore, various light patterns having light spots and dark zones can be formed in accordance with the form of a light or lamp to be created.

In one embodiment, each of the tracks **121**–**126** is formed of a single material, such as a special metal. In another embodiment, each of the tracks **121**–**126** is formed of a multi-layer metal structure (not shown). In this embodiment, the track structure may include a copper layer, a nickel layer on top of the copper layer, and a gold layer on top of the nickel layer. Alternatively, some of the tracks may have the multi-layer structure while others may have a single metal layer.

In the multi-layer structure, the copper layer provides a good material for forming the circuit shape, the nickel layer helps preventing copper migration and provides additional strength, and the gold layer is preferable in wire bonding and both electrical and heat conduction and thereby is very suitable for having the light generating source's attached thereto. According to one embodiment, the copper layer is approximately 17.78 micrometer thick, the nickel layer is between 2.54 to 7.62 micrometer in thickness and the gold layer is at least 0.76 micrometer in thickness. The relatively thick copper layer provides for a sufficient cross-section for corresponding electrical energy supply, the nickel layer is kept relatively thinner in comparison to the copper layer. The gold layer is also kept thinner than the nickel layer in order to save costs.

The heat sink tracks or traces **122** and **125** are between the electrical tracks such that they are parallel to the corresponding anode and cathode tracks. The heat sink tracks **122** and **125** are connected to heat sink frame **108**. With the frame **108**, the heat from the light generating sources **102**–**102***n* is transported to the metal frame **108** via the corresponding heat sink tracks.

FIG. **6** shows the layout of the tracks in accordance with another embodiment. In FIG. **6**, the tracks **141**–**145** include electrical tracks (e.g., the tracks **141**–**144**) and heat sink tracks (e.g., the track **145**). Each of the electrical tracks is of a conductive material (e.g., metal). The tracks may be arranged in a predetermined pattern on the substrate layer **103** in accordance with a desired light form and intensity.

The electrical tracks include a global anode track or trace **141** and a global cathode track or trace **142**. The anode track **141** is connected to all anode terminal tracks (e.g., the terminal track **144**) and the cathode track **142** is connected to all cathode terminal tracks (e.g., the terminal track **143**). An anode terminal and a cathode terminal of a corresponding light generating source are attached to the corresponding tracks. Therefore, various light patterns having light spots and dark zones can be formed in accordance with the form of a light or lamp to be created.

FIG. **6** also shows heat sink tracks (e.g., the track **145**). Each of the heat sink tracks is placed between a pair of terminal tracks. For example, the heat sink track **145** is placed between a pair of terminal tracks and the terminal track pair **143**–**144** sandwiches a heat sink track. In addition, each heat sink track is of the "□" shape. The heat sink tracks also are connected to the heat sink frame (not shown) that are the opposite side of the substrate **103** on which the heat sink tracks are not located. This connection can be made via heat sink via holes (also not shown in FIG. **6**).

Referring to FIGS. **1**–**6**, the solid-state light generating sources **102**–**102***n* of the illumination unit **100** are small surface mountable light generating sources and may include heat sink. The light generating sources **102**–**102***n* emit a broad-spectrum light. The light generating sources **102**–**102***n* are arranged (e.g., attached using the Surface Mounting Technology) on the flexible substrate **103** along the tracks (e.g., the tracks **121**–**126** in FIG. **4** or **141**–**145** in FIG. **6**) and are electrically connected to the electrical tracks (e.g., the tracks **121**, **123**–**124**, and **126** in FIG. **4** or the tracks **141**–**144** in FIG. **6**).

The solid-state light generating sources **102**–**102***n* can be implemented in various ways. Each of the solid-state light generating sources **102**–**102***n* can be a high power surface mountable light generating source. In one embodiment, each of the light generating sources **102**–**102***n* is a LED. In another embodiment, each of the light generating sources **102**–**102***n* is a laser diode. In a further embodiment, each of the light generating sources **102**–**102***n* is an organic LED. In a yet further embodiment, the light generating sources **102**–**102***n* can be a combination of LEDs, laser diodes, and organic LEDs.

When each of the light generating sources **102**–**102***n* is a LED or laser diode, the diode can be a diode chip or a diode package. If the diode is a diode package, it can be a PCB (Printed Circuit Board)-based diode package, a ceramic-based diode package, a leadframe-based diode package, a model-based diode package, or a metal-based diode package. Each of the diode packages has a built-in heat sink to enhance heat dissipation generated by a diode within the diode package. In one embodiment, the diode package also includes a reflector cup that reflects light and an optically designed dome shape to channel out the light at a predetermined viewing angle. Moreover, the diode within a diode package may be covered with luminescent material (e.g., phosphor) to convert the light generated by the diode in certain wavelength to light of other certain wavelength or wavelengths.

In one embodiment, each of the solid-state light generating sources **102**–**102***n* is a High Flux SMT (Surface Mounting Technology) LED manufactured by Agilent Technologies, Inc. of Palo Alto, Calif. (part number HSMZ-C4A0-TW001). This SMT LED is a PCB based LED package having a built-in heat sink copper pad at the bottom. Alternatively, other types of light generating sources can be used.

In another embodiment, each of the light generating sources **102**–**102***n* represents a color pixel that includes at least three light generating sources emitting in the red, green, and blue colors. The three light generating sources are closely packed to form the color pixel. In this case, the optical output intensity of the three colored light generating sources can be controlled to generate any desired color.

The flexible encapsulant **101** encapsulates the light generating sources **102**–**102***n* on the substrate **103** such that the illumination unit **100** is both thin and flexible. The encapsulant **101** is optically transparent and can be clear in color or tinted with a color (e.g., red). The encapsulant **101** is low thermal conductive.

In one embodiment, the encapsulant **101** is made of silicone. In this case, the silicon encapsulant can be biocompatible silicone. In another embodiment, the encapsulant **101** is an epoxy.

In one embodiment, the encapsulant **101** is body compatible. In another embodiment, the encapsulant **101** is not body compatible.

Moreover, the illumination unit **100** may include other electrical or electronic components (not shown) mounted on the substrate **103**. These components may include resistors, capacitors, transistors, current regulators, and other integrated circuit chips. In one embodiment, when the solid-state light generating sources **102**–**102***n* are LEDs, the components may include LED drivers that are capable of controlling the brightness of LEDs in certain areas of the illumination unit **100**.

Referring to FIGS. **1**–**3**, the light generating sources **102**–**102***n* are mounted on and along the respective electrical tracks. Each of the light generating sources **102**–**102***n* is mounted in such a way that an anode terminal (not shown) of the light generating source is electrically connected to its corresponding anode track on the substrate **103**, such as by soldering using screening technique or gluing, and a cathode terminal (not shown) of the light generating source is electrically connected to the corresponding cathode track on the substrate **103**.

In one embodiment, each of the light generating sources **102**–**102***n* is attached to the corresponding electrical tracks using the Surface Mounting Technology (SMT). This makes the illumination unit **100** an SMT-light generating source-package-on-flexible-substrate assembly.

FIG. **5** shows a cross-sectional view of a portion of the illumination unit **100**, showing how each of the light generating sources **102**–**102***n* is mounted on the tracks on the flexible substrate **103** that is attached to the plate **105** via the adhesive tape **104**. As can be seen from FIG. **5**, solder paste is deposited on the exact locations of the anode and cathode tracks **131**–**132** using, for example, screening techniques. Thermally conductive glue is also applied to the heat sink track **133** using, for example, dispensing technique. The light generating source **102***i* is then placed onto the respective electrical tracks **131**–**132**, with the anode and cathode terminals of the light generating source **102***i* corresponding to the solder paste deposited on the anode and cathode tracks **131**–**132**. The light generating source **102***i* is so placed such that its heat sink is in contact with the thermally conductive glue deposited on the heat sink track **133**. The light generating source **102***i* is subsequently secured on the tracks **131**–**133** by re-flow soldering of the solder paste and curing the thermally conductive glue, respectively.

Referring back to FIGS. **1**–**3**, the encapsulant **101** is coated on the substrate **103**, encapsulating the light generating sources **102**–**102***n*. The encapsulant **101** is provided to prevent shortage of the electrical circuit and light generating sources **102**–**102***n*. The encapsulant **101** also provides mechanical and environmental protection to the light generating sources **102**–**102***n*. Besides, the encapsulant **101** also seals the heat dissipation path in order for the surface of the illumination unit **100** to remain at normal temperatures.

In one embodiment, the thickness of the plate **105** is about 0.64 mm (millimeter), the thickness of the substrate **103** is about 0.15 mm, the thickness of each of the light generating sources **102**–**102***n* is about 2.20 mm and the thickness of the encapsulant **101** is about 2.55 mm. This means that the assembled illumination unit **100** has a thickness of about 7.0 mm.

In the foregoing specification, the invention has been described with reference to specific exemplary embodiments thereof. The specification and drawings are, accordingly, to be regarded in an illustrative sense rather than a restrictive sense.

The invention claimed is:

1. An illumination unit, comprising:

a thin and flexible substrate;

a plurality of flexible electrical tracks formed on the flexible substrate;

a plurality of solid-state light source packages arranged on the flexible substrate along the electrical tracks and being electrically connected to the electrical tracks, the light source packages having light generating sources, each light source package having at least one light generating source to generate light, a reflector cup to reflect the light, and an optically designed shape to channel out the light at a predetermined viewing angle; and

a flexible and optically transparent encapsulant to encapsulate the light generating sources on the substrate without leaving any void such that the illumination unit is both thin and flexible.

2. The illumination unit of claim **1**, wherein the encapsulant is made of biocompatible silicone.

3. The illumination unit of claim **1**, wherein encapsulant is clear in color or tinted with dye.

4. The illumination unit of claim **1**, wherein the encapsulant is of low thermal conductivity such that minimized heat is dissipated to the outer surface of the encapsulant.

5. The illumination unit of claim **1**, wherein the light generating sources emit a broad-spectrum light.

6. The illumination unit of claim **1**, wherein the light generating sources are selected from a group comprising fight emitting diodes, laser diodes, and organic light emitting diodes.

7. The illumination unit of claim **6**, wherein the light source packages are selected from a group comprising a PCB (Printed Circuit Board) based diode package, a ceramic-based diode package, a leadframe-based diode package, a modal-based diode package, a metal-based diode package.

8. The illumination unit of claim **7**, wherein the diode package includes a built-in heat sink to help dissipate heat generated by a diode within the diode package.

9. The illumination unit of claim **7**, wherein the light source package further comprises a Light Emitting Diode chip that is covered with luminescent material.

10. The illumination unit of claim **1**, wherein the flexible substrate is made of polyimide material.

11. The illumination unit of claim **1**, wherein the flexible substrate is made of any electrically non-conductive but thermally conductive material.

12. The illumination unit of claim **1**, further comprising a plurality of electronic components arranged on the flexible substrate.

13. The illumination unit of claim **12**, wherein the electronic components are selected from a group comprising resistors, capacitors, transistors, current regulators, and drivers for light emitting diodes.

14. The illumination unit of claim **1**, further comprising at least a heat sink track arranged on the substrate, and an anode track and a cathode track and the heat sink track is formed between the anode and cathode tracks.

15. The illumination unit of claim **14**, further comprising a heat-conducting frame surrounding the substrate, the heat sink track being thermally connected to the frame.

16. The illumination unit of claim **15**, further comprising a heat-conducting sheet attached with the substrate via a thermally conductive adhesive paste and in contact with the heat-conducting frame, wherein the heat-conducting sheet is made of one of metal or ceramic materials.

17. The illumination unit of claim **1**, wherein the electrical tracks are multi-layer tracks that comprise a copper layer on the substrate layer, a nickel layer arranged over the copper layer, and a gold layer over the nickel layer.

18. The illumination unit of claim **1**, wherein each of the light source packages is arranged on the substrate along the electrical tracks using a surface mount technology.

19. The illumination unit of claim **1**, wherein the illumination unit is a display unit.

20. The illumination unit of claim **1**, wherein the illumination unit is used to deliver light energy to the skin of a patient for phototherapy.

21. The illumination unit of claim **1**, wherein the encapsulant is sufficiently thick such that the unit is flexible while providing adequate phototherapy to patient of the unit without harming the patient.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 7,128,442 B2

APPLICATION NO. : 10/760763

DATED : October 31, 2006

INVENTOR(S) : Kian Shin Lee

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 7, Line 30, Claim 6, delete “fight” and insert -- light --.

Signed and Sealed this

Eighth Day of June, 2010

David J. Kappos

Director of the United States Patent and Trademark Office